Project X Update

Steve Holmes

Accelerator Advisory Committee Meeting

November 7, 2011

Outline

- Performance Goals/Requirements
- News since Last AAC
- Reference Design
- R&D Program Goals
- Collaboration
- Timeline
- Response to Prior Recommendations

Our websites:

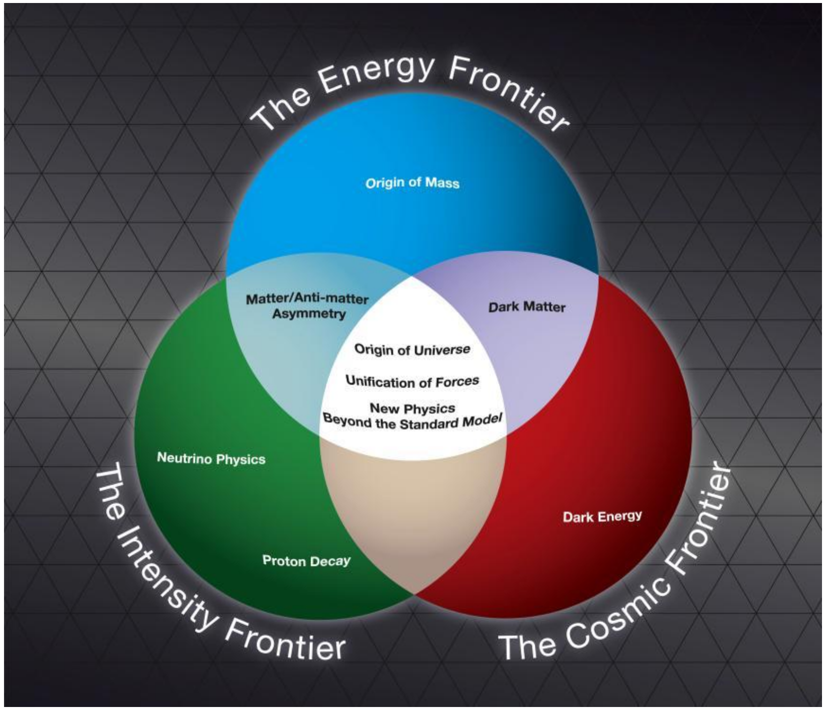
http://projectx.fnal.gov

http://projectx-docdb.fnal.gov

Strategic Context

Fermilab is the sole remaining U.S. laboratory providing facilities in support of accelerator-based Elementary Particle Physics.

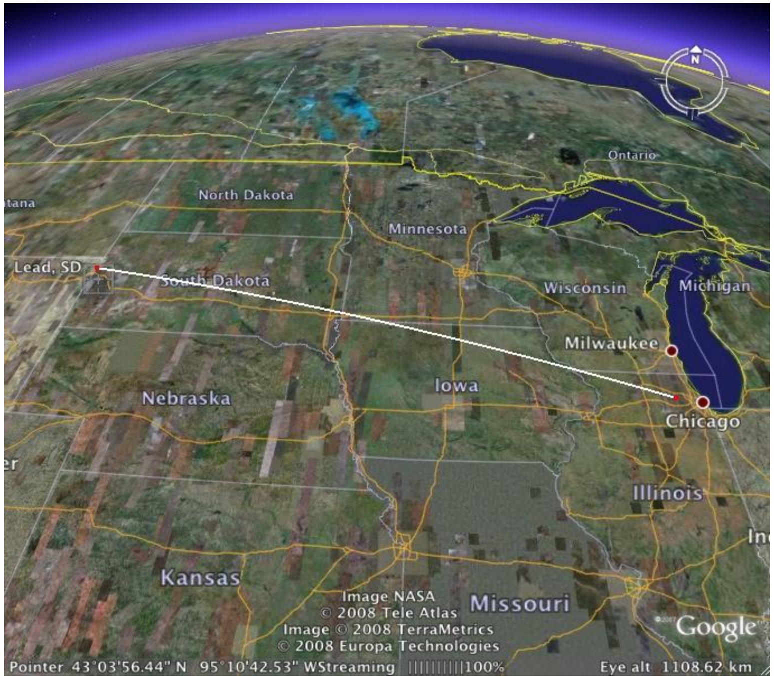
⇒ ***The Fermilab strategy is to mount a world-leading program at the <u>intensity frontier</u>, while using this program as a bridge to an <u>energy frontier</u> facility beyond LHC in the longer term.***



Project X is the key element of this strategy

Performance Goals

- A neutrino beam for long baseline neutrino oscillation experiments
  - 2 MW proton source at 60-120 GeV



- High intensity, low energy protons for kaon, muon, and neutrino based precision experiments
  - Operations simultaneous with the neutrino program
- First step toward a possible future Neutrino Factory and/or a Muon Collider
  - Requires ~4 MW at ~5-15 GeV
- Possible missions beyond EPP
  - Standard Model Tests with nuclei and energy applications

Since July 2010

- Reference Design established as the preferred configuration
  - First discussed at the July 2010 AAC meeting
  - Only minor modifications since then
- CD-0 supporting documentation developed
  - Draft Mission Needs Statement(s)
  - Functional Requirements Specification
  - Reference Design Report
  - RD&D Plan
  - Cost Estimate
  - RLS
- Dennis Kovar retired as Director of OHEP
- Jim Siegrist appointed Director of OHEP
  - Project X briefing (at Fermilab) September 28

Since July 2010

- DOE Briefings
  - November 2010/OHEP
    - Physics program
    - Cost estimate range: $1.7 – 1.8 B
  - December 2010/SC
    - Strategic plan
    - Physics program
  - May 2011/OHEP
    - Mission Needs Statement
    - Physics Program/Workshop Preparations
    - Staging Options
      - 3 GeV CW linac: ~2/3 of total facility cost
    - India Collaboration

Since July 2010

- Indian Institutes Fermilab Collaboration (IIFC) Workshop
  - October 2010 at RRCAT, IUAC, BARC, VECC
- India Workshop on Intensity Frontier Physics
  - January 2011 in Mumbai (BARC)
- DOE-DAE Implementing Agreement on "Accelerator and Particle Detector Research & Development for Discovery Science" – signed in July
    - Fermilab, SLAC, JLab, Cornell listed as U.S. participating institutions
    - Specific MOUs will be written underneath this agreement
  - Supplements to IIFC covering rf, cryo, instrumentation implemented
  - Preliminary discussions with India on construction/commissioning phase
- IHEP-Fermilab Workshop on Proton Accelerators
  - February 2011 in Beijing
  - IHEP and IMP/Lanzhou participation
- Activities with ESS and SPL
  - We both provide representation at each other's collaboration meetings

Since July 2010

- Physics Workshops
  - November 2010
  - White papers describing facilities and initial experiments
    - Neutrinos
    - Kaons
    - Muons
    - Nuclear Physics
    - Nuclear Energy

http://www.fnal.gov/directorate/Longrange/Steering_Public/workshop-physics-5th.html

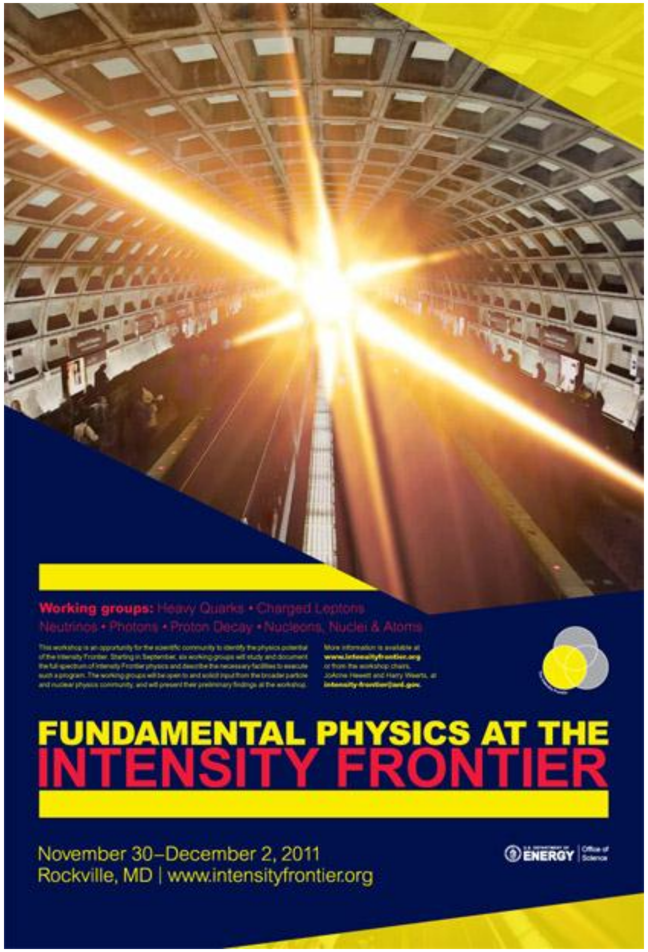
- Project X Lunch Forum, DPF Meeting, August 2011

  http://indico.cern.ch/conferenceTimeTable.py?confId=129980#20110810

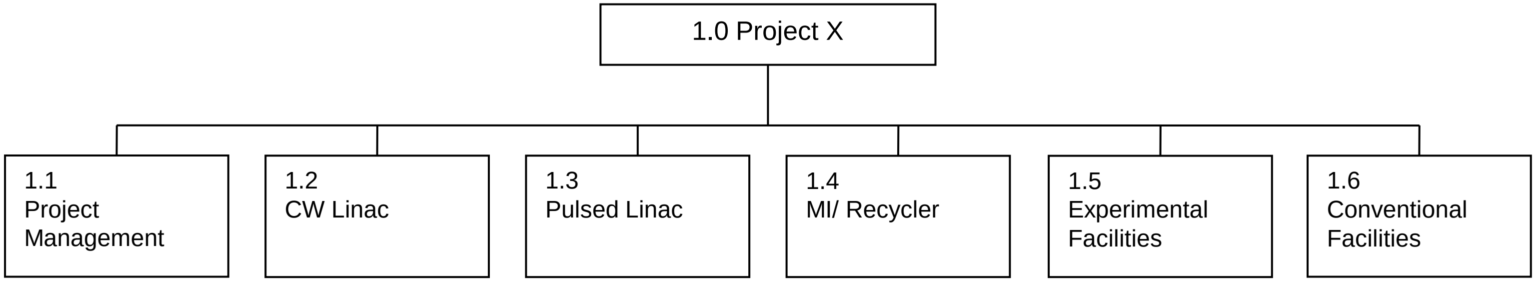
- DOE Intensity Frontier Workshop scheduled December 2011

DOE Intensity Frontier Workshop

- Nov 30 – Dec 2, Rockville, MD
  - Not a Project X workshop although expect PX to be very significant presence
  - Focus on opportunities for U.S. leadership: both particle and nuclear physics research
  - Engagement with Energy and Cosmic Frontier proponents
  - Co-chairs: JoAnne Hewett/SLAC, Harry Weerts/ANL,
  - Proton performance parameters for the next two decades at Fermilab provided to the chairs
  - Accelerator/detector technology WG being established



Current Organization



- Project Office

Project Manager	S. Holmes	Deputy Project Manager	TBD
Project Scientist/Accelerators	S. Nagaitsev	International Coordinator	S. Mishra
Project Scientist/Experiments	R. Tschirhart	Budgeting/Scheduling	E. Peoples
Project Engineer	J. Kerby	Financials	M. Smith

- Level 2

CW Linac	R. Kephart, V. Lebedev
Pulsed Linac	N. Solyak
Main Injector/Recycler	I. Kourbanis
Experimental Facilities	R. Tschirhart

- Level 3

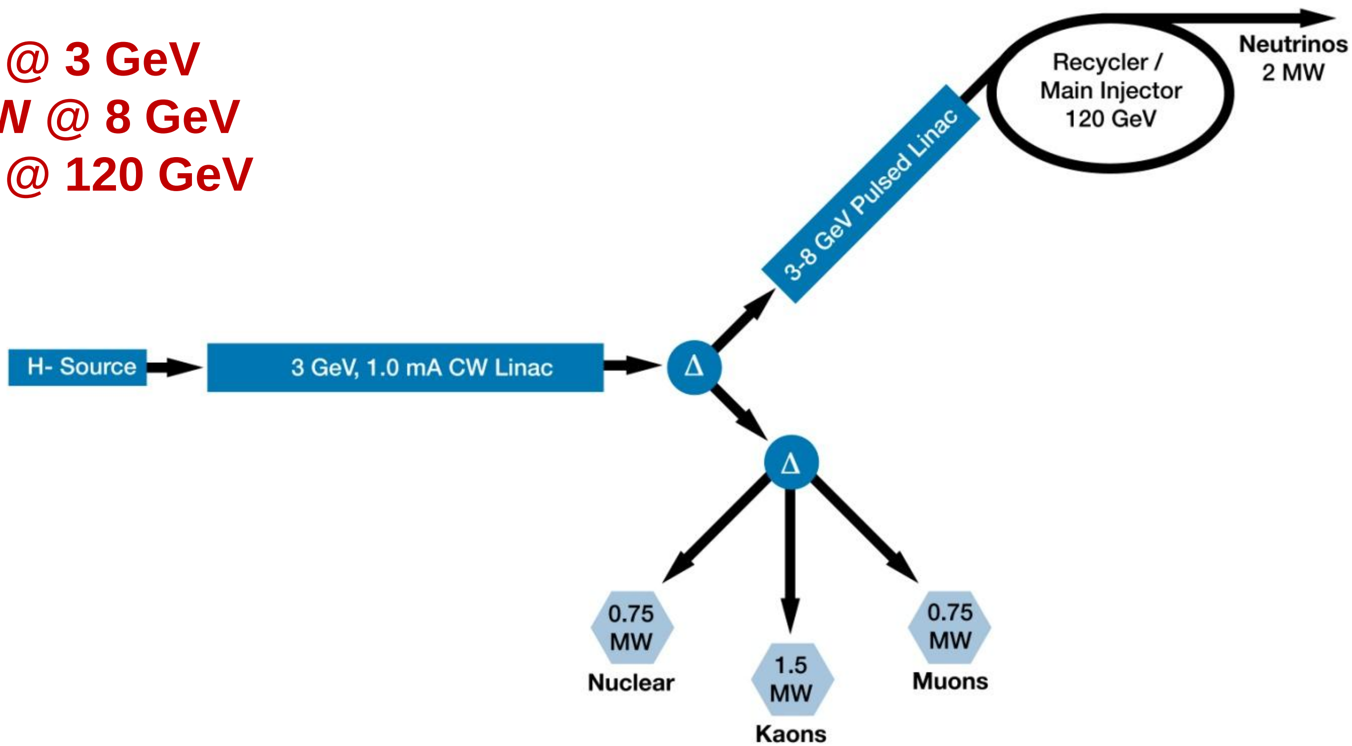
  Complete complement assigned

Since July 2010

- Technical Board established with cross-collaboration membership
  - Advisory to the Project Scientist for Accelerator Facilities
  - Current representation includes Fermilab, JLab, SLAC, ANL, LBNL, India
  - Decision on HWR vs SSR0
- Task Forces established to look at future connections
  - Muon Collider Task Force – K. Gollwitzer
    - Jointly sponsored by PX and MAP
  - Muons @ PX Task Force – E. Prebys, V. Lebedev
- FY2012 appropriations bills reported out of committee in House and Senate
  - Senate bill asks OHEP for an Intensity Frontier strategy by June (180 days from bill enactment) specifically addressing:
    - "expected benefits of intensity frontier science"
    - "a strategy for maintaining the U.S. lead"
    - "funding needs over the next ten years, including construction activities"
- Project X FY2012 budget established at $13.0M
  - FY2011 = $10.5M

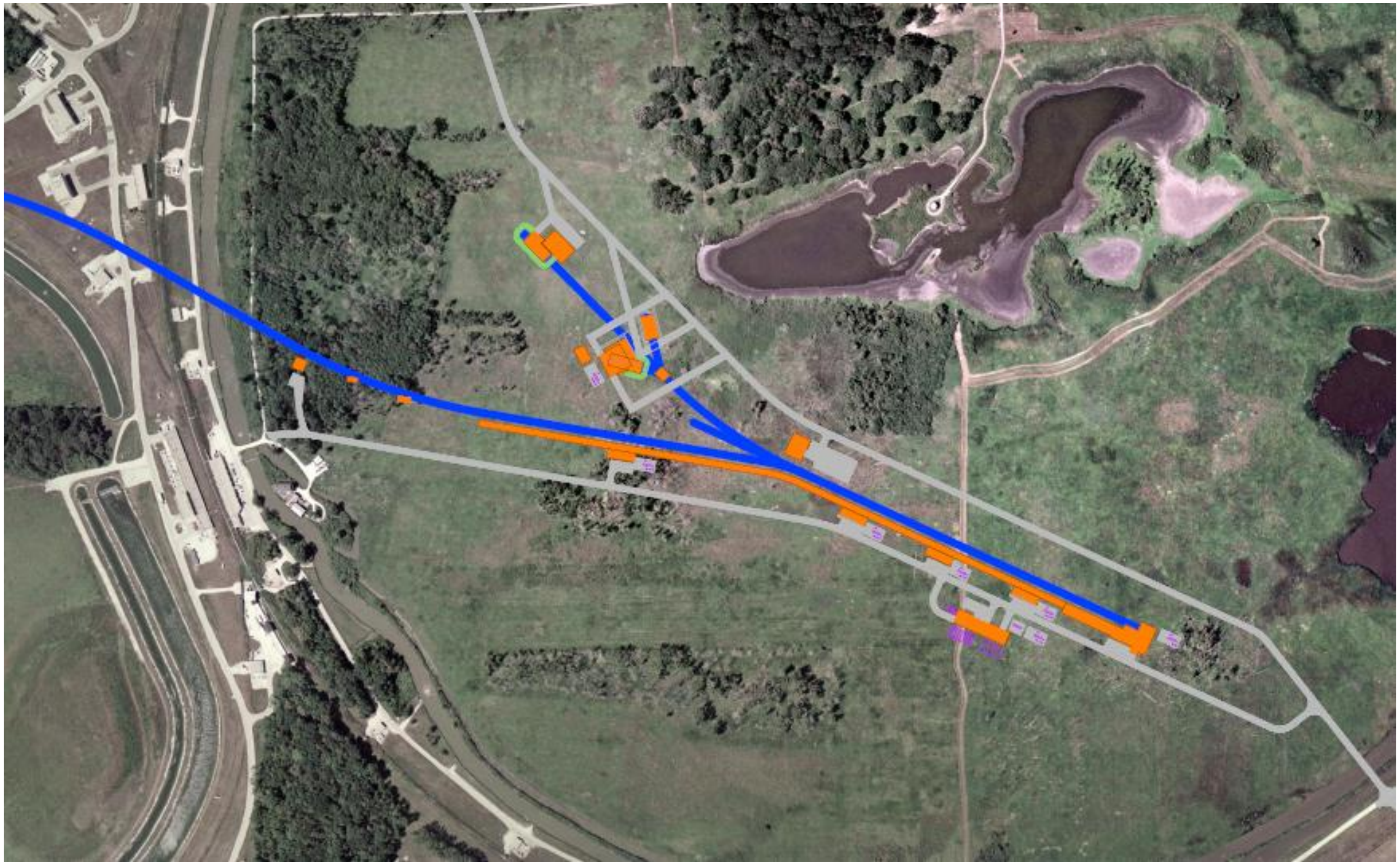
Reference Design

3 MW @ 3 GeV
200 kW @ 8 GeV
2 MW @ 120 GeV



- Reference Design supports all mission elements
- Stable for more than a year

Reference Design Site



Project X

Functional Requirements Specification

Requirement	Description	Value
L1	Delivered Beam Energy, maximum	3 GeV (kinetic)
L2	Delivered Beam Power at 3 GeV	3 MW
L3	Average Beam Current (averaged over >1 μsec)	1 mA
L4	Maximum Beam Current (sustained for <1 μsec)	5 mA
L5	The 3 GeV linac must be capable of delivering correctly formatted beam to a pulsed linac, for acceleration to 8 GeV	
L6	Charge delivered to pulsed linac	26 mA-msec in < 0.7 sec
L7	Maximum Bunch Intensity	1.9×10^{8}
L8	Minimum Bunch Spacing	6.2 nsec (1/162.5 MHz)
L9	Bunch Length	<50 psec (full-width half max)
L10	Bunch Pattern	Programmable
L11	RF Duty Factor	100% (CW)
L12	RF Frequency	162.5 MHz and harmonics thereof
L13	3 GeV Beam Split	Three-way
L14	Beam Particles	H-
P1	Maximum Beam Energy	8 GeV
P2	The 3-8 GeV pulsed linac must be capable of delivering correctly formatted beam for injection into the Recycler Ring (or Main Injector).	
P3	Charge to fill Main Injector/cycle	26 mA-msec in <0.7 sec
P4	Maximum beam power delivered to 8 GeV	350 kW
P5	Duty Factor (initial)	4.3%

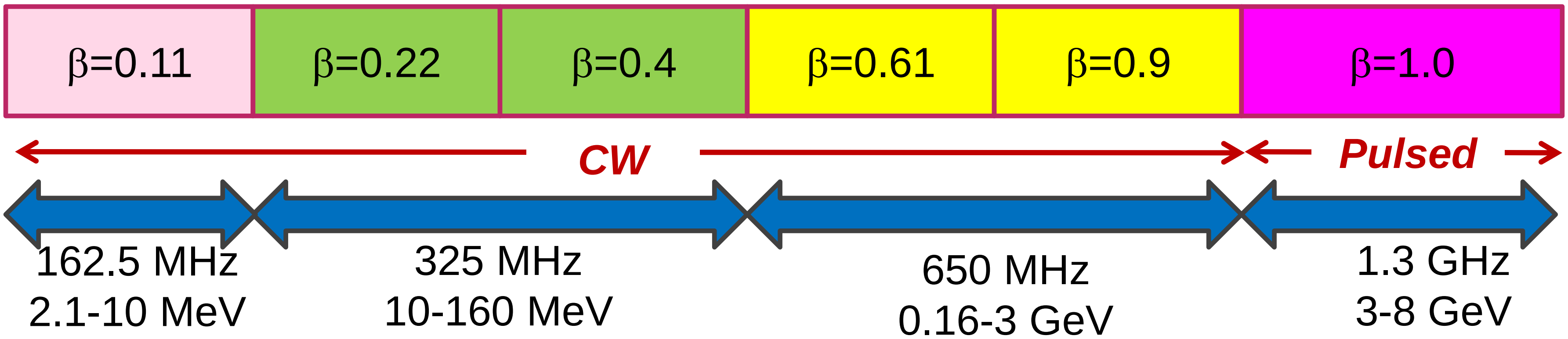
Functional Requirements Specification

Requirement	Description	Value
M1	Delivered Beam Energy, maximum	120 GeV
M2	Delivered Beam Energy, minimum	60 GeV
M3	Minimum Injection Energy	6 GeV
M4	Beam Power (60-120 GeV)	> 2 MW
M5	Beam Particles	Protons
M6	Beam Intensity	1.6×10^{14} protons per pulse
M7	Beam Pulse Length	~10 μsec
M8	Bunches per Pulse	~550
M9	Bunch Spacing	18.8 nsec (1/53.1 MHz)
M10	Bunch Length	<2 nsec (fullwidth half max)
M11	Pulse Repetition Rate (120 GeV)	1.3 sec
M12	Pulse Repetition Rate (60 GeV)	0.7 sec
M13	Max Momentum Spread at extraction	2×10^{-3}
I1	The 3 GeV and neutrino programs must operate simultaneously	
I2	Residual Activation from Uncontrolled Beam Loss in areas requiring hands on maintenance.	<20 mrem/hour (average) <100 mrem/hour (peak) @ 1 ft
I3	Scheduled Maintenance Weeks/Year	8
I4	3 GeV Linac Operational Reliability	90%
I5	60-120 GeV Operational Reliability	85%
I6	Facility Lifetime	40 years
U1	Provisions should be made to support an upgrade of the CW linac to support an average current of 5 mA.	
U2	Provisions should be made to support an upgrade of the Main Injector to a delivered beam power of ~4 MW at 120 GeV.	
U3	Provisions should be made to deliver CW proton beams as low as 1 GeV.	
U4	Provision should be made to support an upgrade to the CW linac such that it can accelerate Protons.	
U5	Provisions should be made to support an upgrade of the pulsed linac to support a duty factor or 10%.	
U6	Provisions should be made to support an upgrade of the CW linac to a 3.1 nsec bunch spacing.	

RD&D Program

- Goal: Mitigate risk associated with technical, cost, and schedule uncertainties
- The primary elements of the R&D program include:
  - Development of a wide-band chopper
    - Capable of removing bunches in arbitrary patterns at a 162.5 MHz bunch rate
  - Development of an H- injection system
    - Require between 4.4 – 26 msec injection period, depending on pulsed linac scenario
  - Superconducting rf development
    - Six different cavity types at four different frequencies
    - rf sources
    - Long pulse operation at 1.3 GHz
    - Development of partners and vendors
  - Design development
    - Beam and e-m simulations and modeling
    - reliability analysis
    - Upgrade paths: MC and Muons@PX Task Forces
  - Test Facilities
    - Subsequent slide
- Goal is to complete R&D phase by 2016

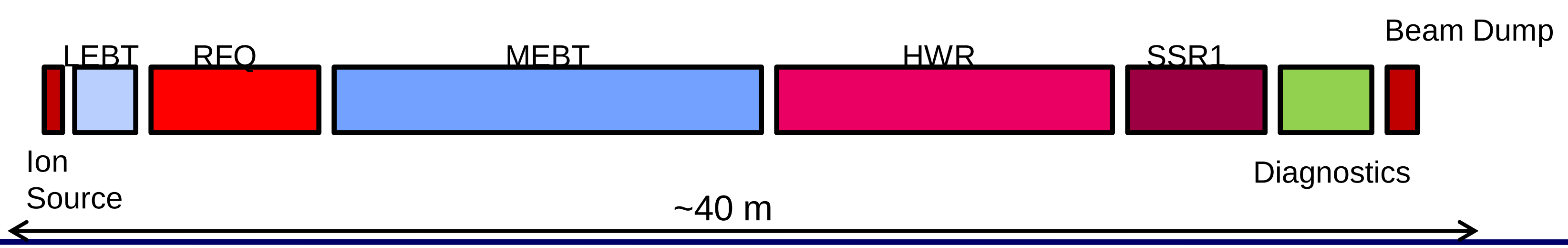
SRF Linac
Technology Map



Section	Freq	Energy (MeV)	Cav/mag/CM	Type
HWR (β_G=0.1)	162.5	2.1-10	9/6/1	HWR, solenoid
SSR1 (β_G=0.22)	325	10-42	16/18/ 2	SSR, solenoid
SSR2 (β_G=0.47)	325	42-160	36/20/4	SSR, solenoid
LB 650 (β_G=0.61)	650	160-460	42 /14/7	5-cell elliptical, doublet
HB 650 (β_G=0.9)	650	460-3000	152/19/19	5-cell elliptical, doublet
ILC 1.3 (β_G=1.0)	1300	3000-8000	224 /28 /28	9-cell elliptical, quad

R&D Test Facilities

- New Muon Lab (NML) facility under construction for ILC RF unit test
- Meson Detector Building (MDB) Test Facility
  - 2.5 MeV beam (p, H-): 1% duty factor, 3 msec pulse
    - Instrumentation development
  - Test stands for dressed cavities at 1.3 GHz, 650 MHz, and 325 MHz
- Project X Injector Experiment PXIE)
  - Prototype of first 10-30 MeV of Project X.
    - Validate PX front end concept ⇒ mitigate primary technical risk within Reference Design.
  - Integrated systems test goals:
    - Full design parameters: 1 mA average current with 80% chopping of beam from RFQ
    - Efficient acceleration with minimal emittance dilution through ~15 MeV
  - Collaboration: Fermilab, ANL, LBNL, SLAC; India & China?
  - Goal: October 2016: Beam accelerated to ~10 MeV with nearly final parameters
  - White paper: http://projectx.fnal.gov/research-and-development.shtml



Collaboration

- Organized as a "national project with international participation"
  - Fermilab as lead laboratory
  - Draft Governance Plan discussed with all collaborating institutions.
- Collaboration MOUs for the RD&D phase outline basic goals, and the means of organizing and executing the work. Signatories:

National		IIFC
ANL	ORNL/SNS	BARC/Mumbai
BNL	MSU	IUAC/Delhi
Cornell	TJNAF	RRCAT/Indore
Fermilab	SLAC	VECC/Kolkata
LBNL	ILC/ART	

- We are utilizing a model of construction phase responsibilities as a guide to R&D assignments
- Informal collaboration/contacts with CERN/SPL, ESS, China, Korea

Timeline

- We have documentation in hand sufficient for CD-0

- Working Timeline (not approved by DOE)

CD-0	FY 2012
CD-1	FY 2013
CD-2	FY 2014
CD-3	FY 2016
CD-4	FY 2021

Primary Goals through 2016

- Project Management
  - Maintain all documentation in a “ready to proceed” state
  - Complete Project X baseline: technical, cost, schedule
  - Complete NEPA documentation and permit sign-offs
  - Functional, certified EVMS
  - Complete concepts for utilization of PX as platform for a muon-based facility
  - Coordinate all collaboration activities
    - Execute collaboration MOU for the construction phase

Primary Goals through 2016

- CW Linac
  - Complete installation and initiate operations of PXIE
    - Demonstrate required chopper performance
  - Complete CW linac design
    - Includes complete designs of all systems
    - Functional requirements, design, and interface specifications for all components
  - Complete and successfully test prototypes of critical components
    - RF sources
    - One cavity of each type through horizontal test
    - One cryomodule at each frequency
    - Diagnostics, LLRF, cryo, controls, etc.
  - Understand the role of every collaborator during the construction phase
    - Includes documented deliverables
  - Complete acquisition strategy
    - Qualified vendors as required
- Pulsed Linac: same list except
  - No systems test with protons
  - Decision on linac energy
  - Decision on linac pulse length

Primary Goals through 2016

- Main Injector/Recycler
  - Complete MI/Recycler design
    - Decision on H- injection scheme may remove Recycler
    - Includes complete designs of all systems
    - Functional requirements specifications, design specifications, interface specifications for all components
  - Complete and successfully test prototypes of critical components
    - H- injection system
    - In-situ beam coating
    - rf cavity and power amplifier (fundamental and second harmonic)
    - Diagnostics, LLRF, etc.
  - Understand the role of every collaborator during the construction phase
    - Includes documented deliverables
  - Complete acquisition strategy
    - Qualified vendors as required

Primary Goals through 2016

- Experimental Facilities
  - Identification of day one experiments and facilities
  - Complete experimental areas design
    - Functional requirements specifications, design specifications, interface specifications for all components
  - Complete and successfully test prototypes of critical components
    - 3 GeV beam splitter
    - Multi-MW target technologies
    - Detector technologies (off-project?)
- Conventional Facilities
  - Master planning as relate to PX siting and utility needs
    - Consolidation of new project (LBNE, MU2E, PX, g-2) infrastructure
  - General support of alternate configurations, value engineering and phasing options
  - Complete facilities design and supporting bid packages
    - Site prep, roads, etc.
    - Enclosures and surface buildings
    - Electrical, ICW, LCW, HVAC
  - Support for NEPA documentation

Resources
FY2012 Budget

1.0 Project X

1.1 Project Management	1.2 CW Linac	1.3 Pulsed Linac	1.4 MI/ Recycler	1.5 Experimental Facilities	1.6 Conventional Facilities
FTE 6.0	FTE 17.5	FTE 4.35	FTE 3.6	FTE 2.2	FTE 0
M&S $300	M&S $2310	M&S $50	M&S $200	M&S $130	M&S $170
Collab $0	Collab $450	Collab $0	Collab $250	Collab $0	Collab $0
MR $200					

Note: Dollar amounts are direct

- $600K of collaborator funding in 1.2 forward funded in FY11
- New WBS consistent with what we will use as a project
- FY12 budget developed within this WBS, and new set of task codes implemented 10/1/11

Response to Prior Recommendations

10-AAC-27	Accelerator Advisory Cmte Meeting	Open	Reformulate the Project X muon goal from "Develop Project X to serve as the front end of future facilities like a Neutrino Factory or Muon Collider" to "Develop Project X as a first step towards future facilities like a Neutrino Factory or Muon Collider."	Holmes	11/1/2011	Wording modfied. Project X and MAP have established a joint Task Force to identify feasible paths for upgrading/improving Project X to meet the needs of a Neutrino Facotry or Muon Collider.
10-AAC-28	Accelerator Advisory Cmte Meeting	Open	Acceleration from 3 to 8 GeV with a pulsed superconducting linac is preferable: i) It will allow experimenting with 8 GeV H- injection in a ring, first at the 200 kW level in the Recycler for the LBNE program, and afterwards on potential future test set-up(s) investigating alternative charge exchange and accumulation schemes, ii) it could become a significant portion (100's of M$) of a future multi-MW proton driver.	Holmes	11/1/2011	The pulsed linac has been adopted as the 3 to 8 GeV accelerator within the Project X Reference Design. A concept exists for upgrading to 4 MW at 8 GeV: 5 mA x 6.6 msec x 15 Hz.
10-AAC-29	Accelerator Advisory Cmte Meeting	Open	Design the infrastructure of Project X with margin for future high-power upgrades (space for RF systems, radiation shielding…).	Holmes	11/1/2011	The Functional Requirements Specification for Project X defines a set of upgradability characteristics including, 5 mA average current and 10% duty factor operations in the 8 GeV linac (among others)
10-AAC-30	Accelerator Advisory Cmte Meeting	Open	Establish the list of subjects that need to be investigated for demonstrating the feasibility of the technologies needed for the proton driver of an NF or MC. Define how they could be addressed with Project X, possibly marginally influencing its design.	Holmes	11/1/2011	This is part of the charge of the Project X-Muon Collider Task Force. The report is due 12/31/11 - see talk by Keith Gollwitzer at the November 2011 AAC meeting.
10-AAC-31	Accelerator Advisory Cmte Meeting	Open	Considering the difficulty of the challenge, imagine intermediate steps (e.g. implementing a 1 MW device before attempting full power.)	Holmes	11/1/2011	This referes to implementation steps on the path towards a Muon collider front end.
10-AAC-32	Accelerator Advisory Cmte Meeting	Open	Check feasibility of the preferred solution for Project X.	Holmes	11/1/2011	We have found nothing that would impugn the feasibility of the Reference Design. The critical elements are the choppers, the H- injection system, and the srf systems
10-AAC-33	Accelerator Advisory Cmte Meeting	Open	Focus on designing in detail the Project X accelerators and their components. That includes sc cavities and related auxiliary equipment, beam chopper, collimators and dumps, H^- charge exchange injection at 8 GeV in the Recycler, stability of high intensity beam in the Recycler and Main Injector, etc.	Holmes	11/1/2011	Significant progress has been made on all these fronts. In general we would characterize the Reference Design as having a level of technical detail that is well beyond what is traditional at the time of CD-0.

Summary

- Project X is central to the future strategy for U.S. accelerator based particle physics
  - Intensity frontier leadership for decades: neutrinos and rare processe
  - Applications beyond elementary particle physics;
- Reference Design established as preferred concept
  - 5 MW beam power available
    - 3MW at 3 GeV for rare processes
    - 2 MW at 60-120 GeV for long baseline neutrinos
  - CW linac is unique for this application, and offers capabilities that would be hard/impossible to duplicate in a synchrotron
  - Configuration stable for 18 months
- Documentation in hand sufficient for CD-0
- Well targeted R&D program that is addressing the major technical challenges
- Collaboration in place for the R&D phase
  - Potential for significant international in-kind contributions to construction phase
- We are prepared to construct Project X over the period 2016 – 2020
  - Staging opportunities exist

Backup Slides

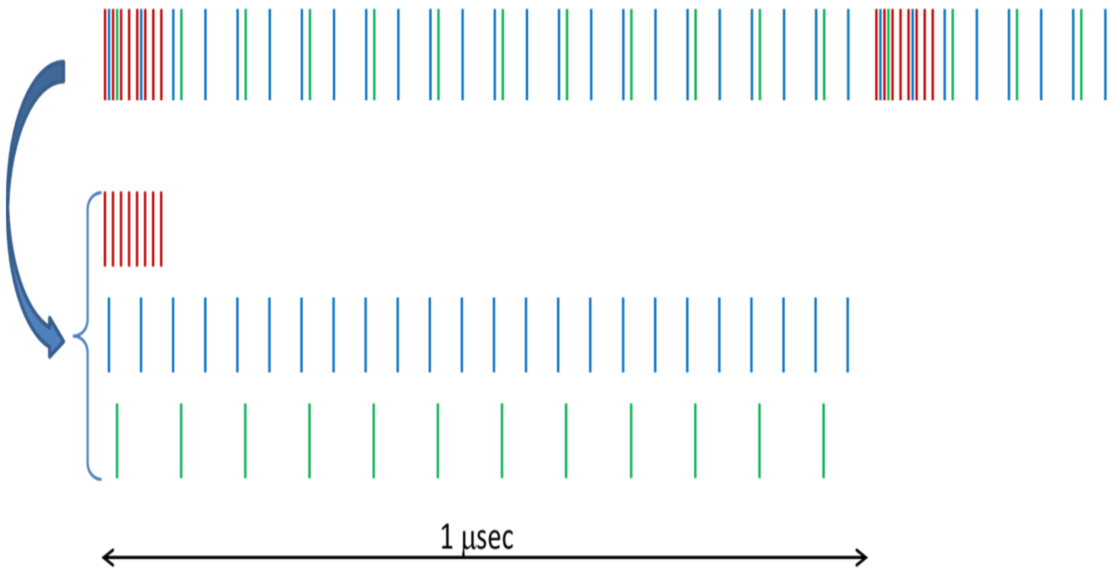
Operating Scenario
3 GeV Program

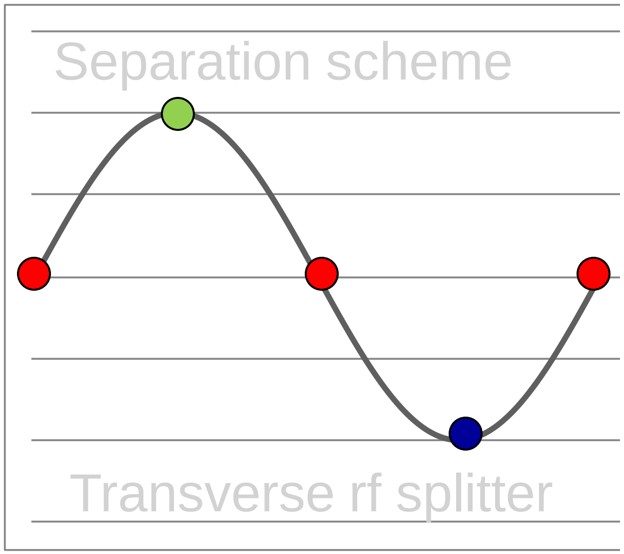
<u>1 μsec period at 3 GeV</u>

Muon pulses (12e7) 162.5 MHz, 80 nsec	700 kW
Kaon pulses (12e7) 27 MHz	1540 kW
Nuclear pulses (12e7) 13.5 MHz	770 kW

Ion source and RFQ operate at 4.2 mA

70% of bunches are chopped @ 2.1 MeV ⇒ maintain 1 mA over 1 μsec





Reference Design
How did we get here?

- Three Project X configurations have been developed, in response to limitations identified at each step:
  - Initial Configuration-1 (IC-1)
    - 8 GeV pulsed linac + Recycler/MI
    - Fully capable of supporting neutrino mission
    - Limited capabilities for rare processes
  - Initial Configuration-2 (IC-2)
    - 2 GeV CW linac + 2-8 GeV RCS + Recycler/MI
    - Fully capable of supporting neutrino mission
    - 2 GeV too low for rare processes (Kaons)
    - Ineffective platform for Neutrino Factory or Muon Collider
  - Reference Design
    - 3 GeV CW linac + 3-8 pulsed linac + Recycler/MI
    - Ameliorates above deficiencies